PRISM/PRIME

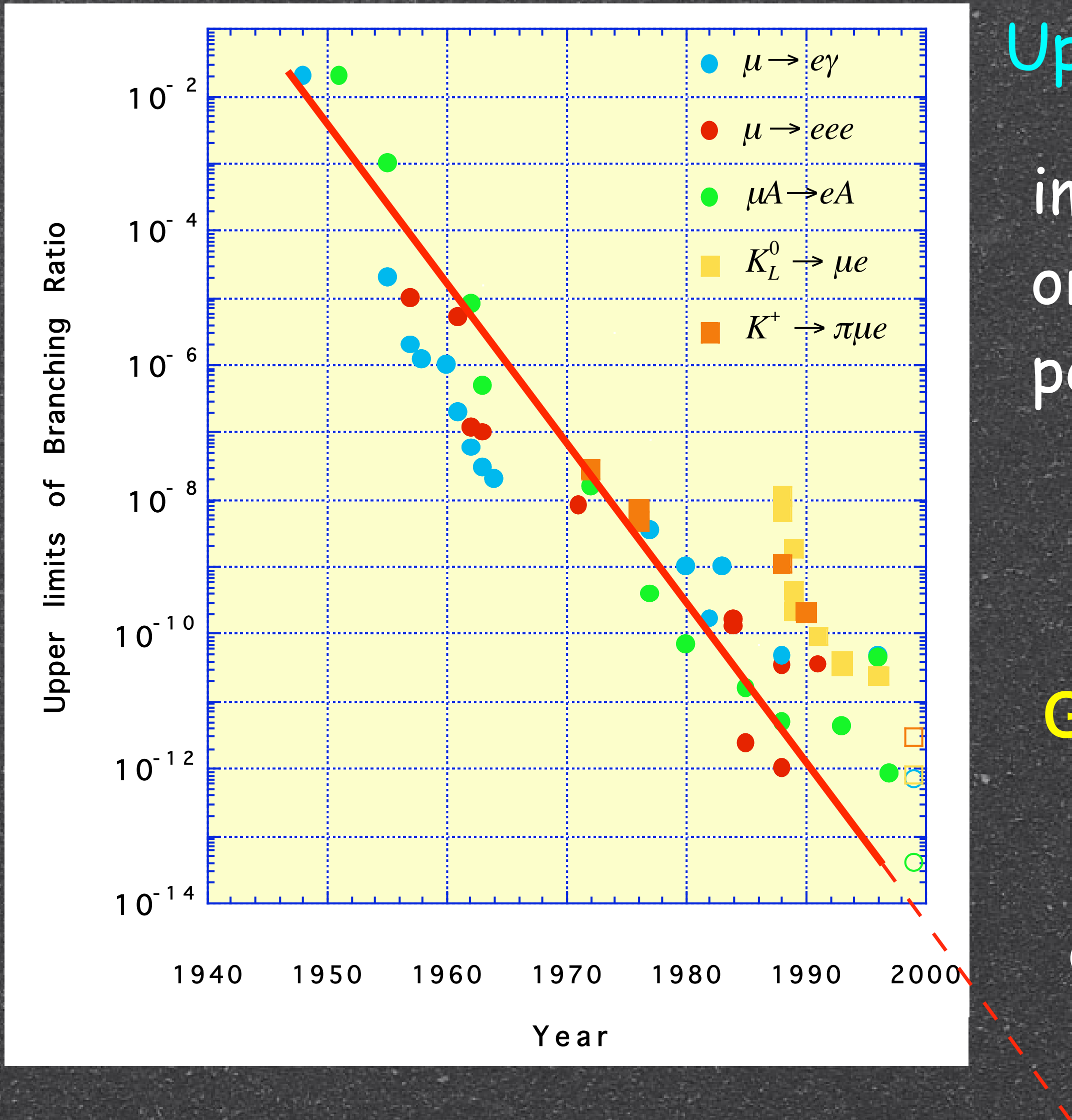
Akira Sato

Osaka University

outline

- mu-e conv.
- PRISM : high intensity mu source
  - Overview
  - Proton driver
  - PRISM-FFAG
- PRIME : mu-e conv. experiment
  - Spectrometer
  - Sensitivity

History of LFV searches



Upper limits of Searches

improved by two orders of magnitude per decade.

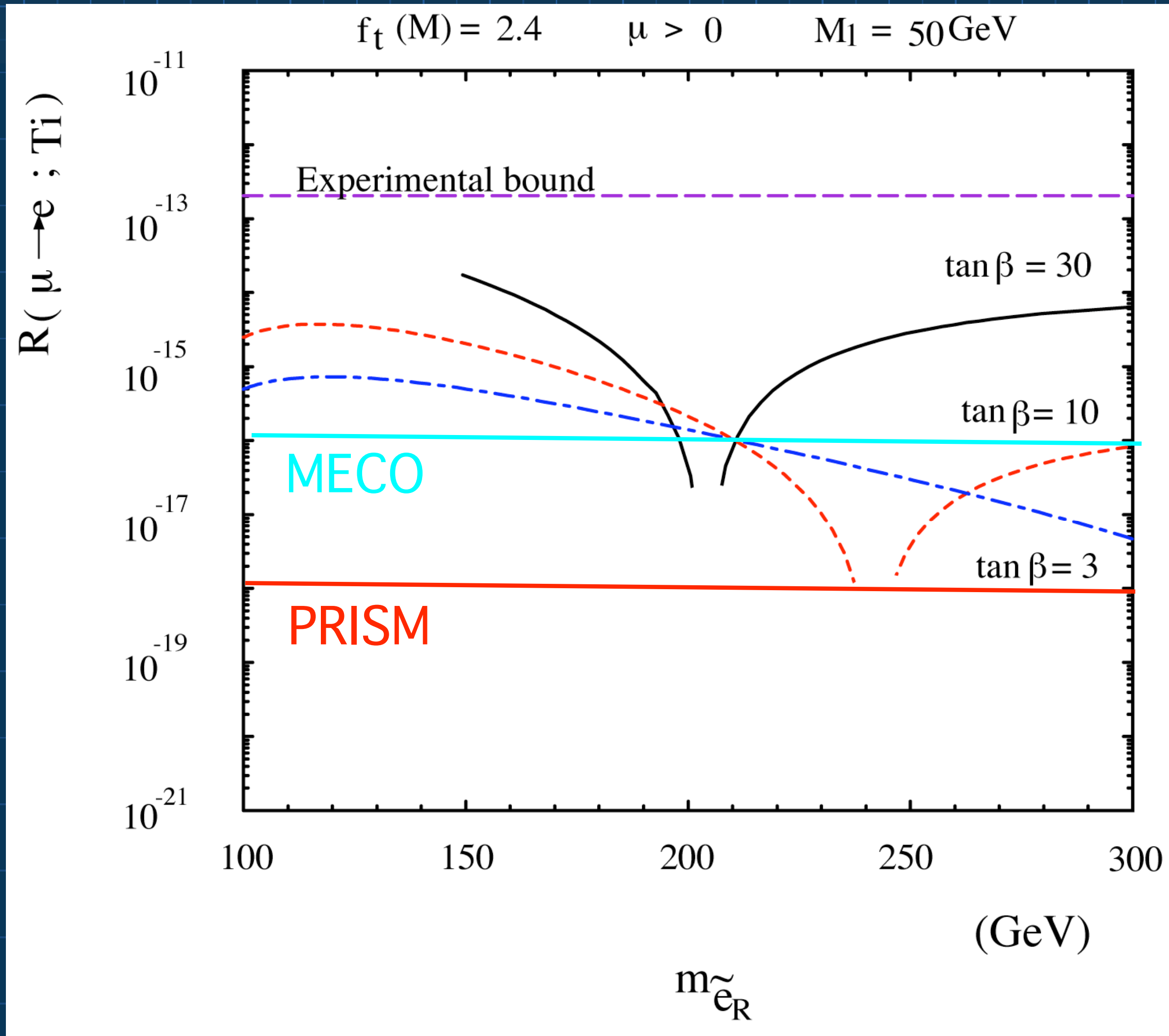
Goal of PRISM/PRIME

BR(μA->eA)~10^{-18}

coming to

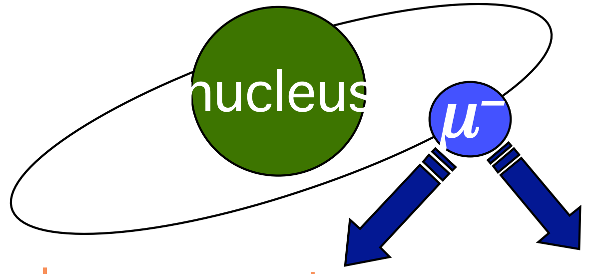
10^{-16} to 10^{-18}

SUSY-GUT prediction



μe conversion in a Muonic Atom

- muonic atom (1s state)



nuclear muon capture
$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$

muon decay in orbit
$\mu^- \rightarrow e^- \nu \bar{\nu}$

- neutrinoless muon nuclear capture (= μ-e conversion)

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

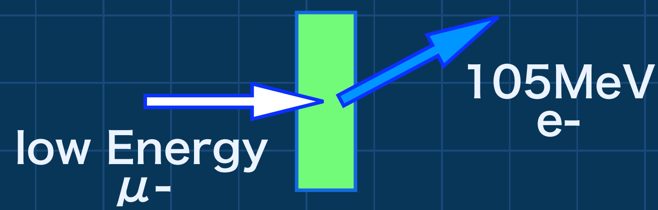
coherent process

$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

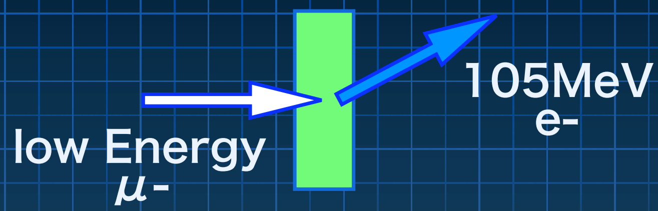
lepton flavors changes by one unit.

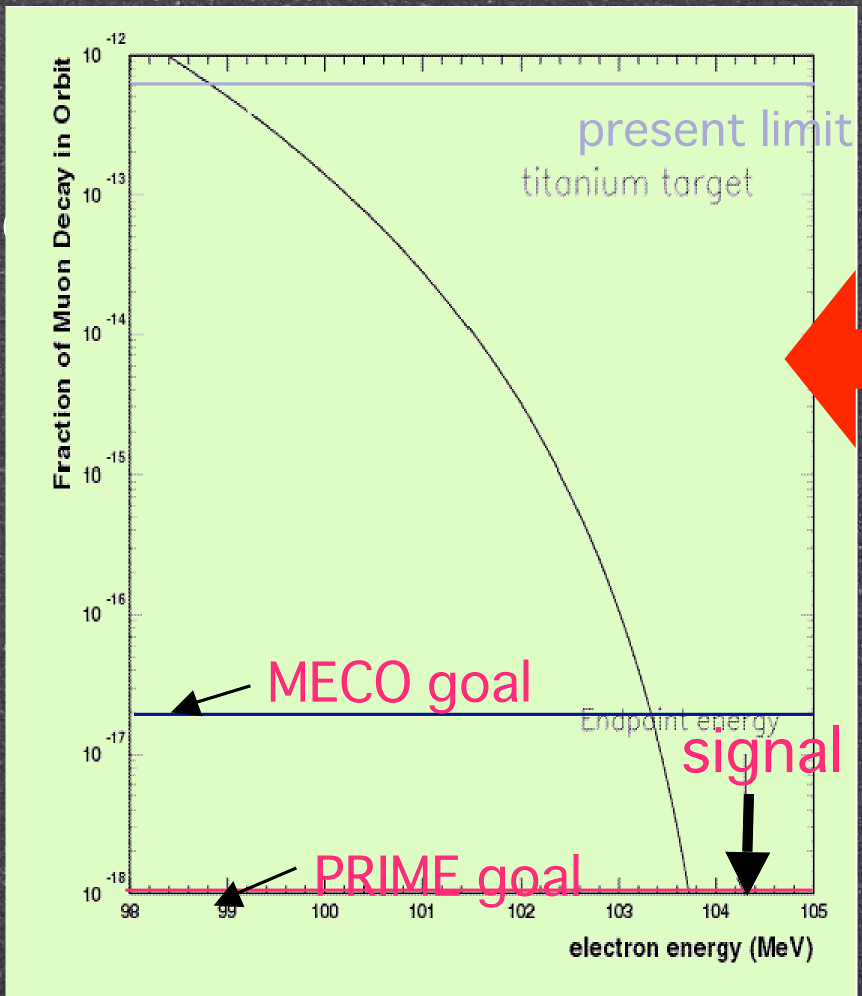
stopped μ experiment

higher intensity muon



μe-conversion signal & backgrounds





narrow energy spread

- Backgrounds
  - muon decay in orbit
    - endpoint comes to the signal
    - $\propto (\Delta E)^5$
  - radiative muon capture
  - radiative pion capture
    - pulsed beam required
    - wait until pions decay.
  - cosmic rays

no pion contami.

  - and many others.

μ beam requirements for the next gene. experiments

Higher muon intensity

more than $10^{12}\mu$/sec

Pulsed beam

rejection of b.g. from proton beam

Narrow energy spread

allow thinner muon-stopping target

-> better e^- resolution

Less beam contamination

no pion contamination

beam extinction between pulses

MECO@BNL

BR $\sim 10^{-16}$

PRISM

BR $\sim 10^{-18}$

PRISM

Phase Rotated Intense Slow Muon source

High Intensity — high power p beam, super cond. solenoid pi capture

- **intensity : 10^{11}-10^{12} $\mu^{\pm}$/sec**
- **beam repetition : 100-1000Hz**
- **muon kinetic energy : 20 MeV (=68 MeV/c)**

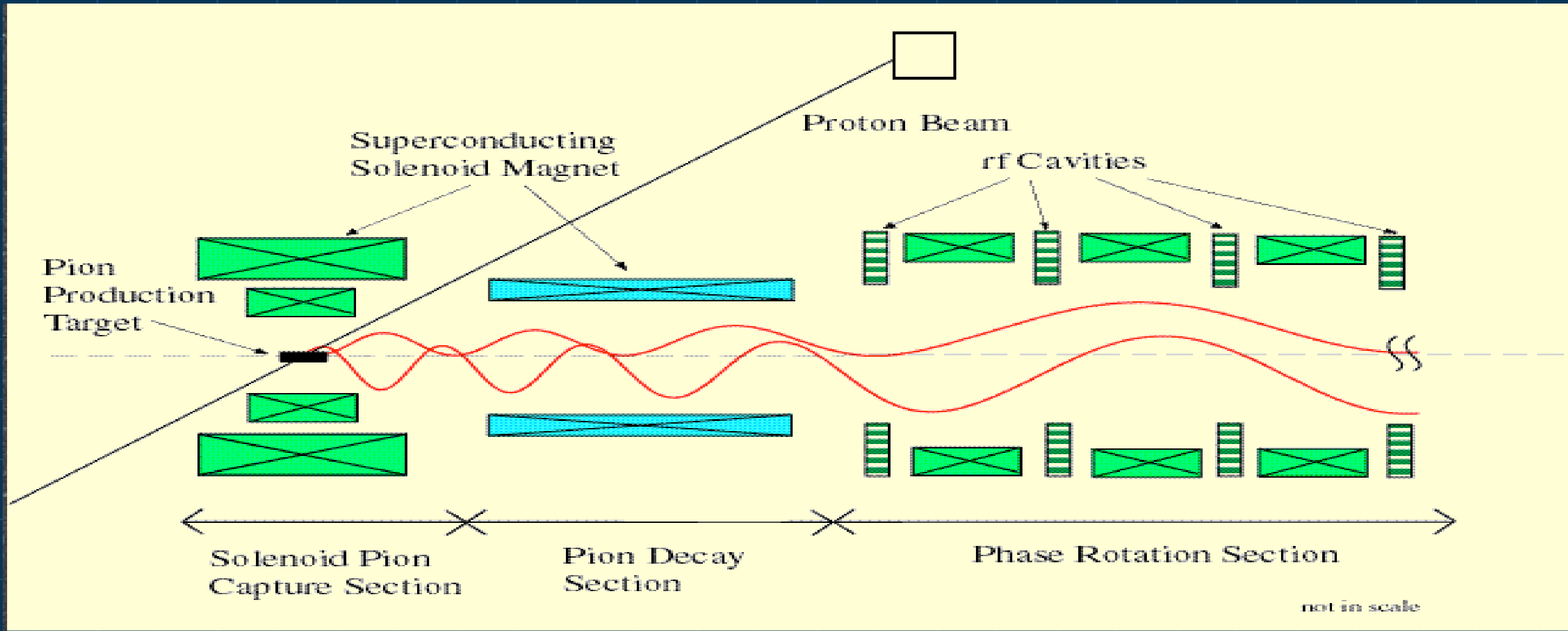
Narrow energy spread — phase rotation

- **kinetic energy spread : ±0.5-1.0 MeV**

Less beam contamination — long beam line

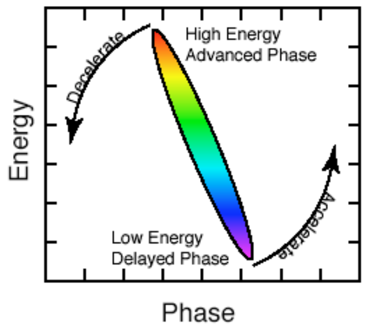
- **π contamination < 10^{-18}**

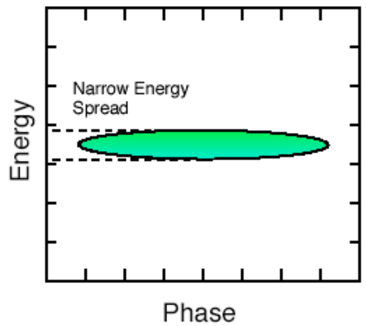
Conceptual Structure of PRISM



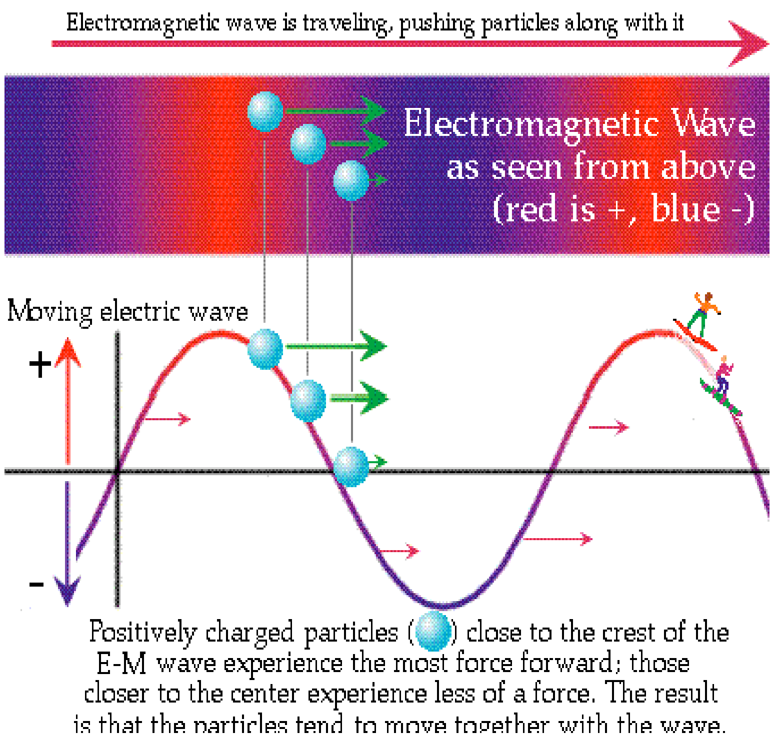
Phase Rotation

- Phase Rotation = decelerate particles with high energy and accelerate particle with low energy by high-field RF





proton beam is needed to ensure that high-energy particles come early and low-energy one come late.



PRISM
FFAG based

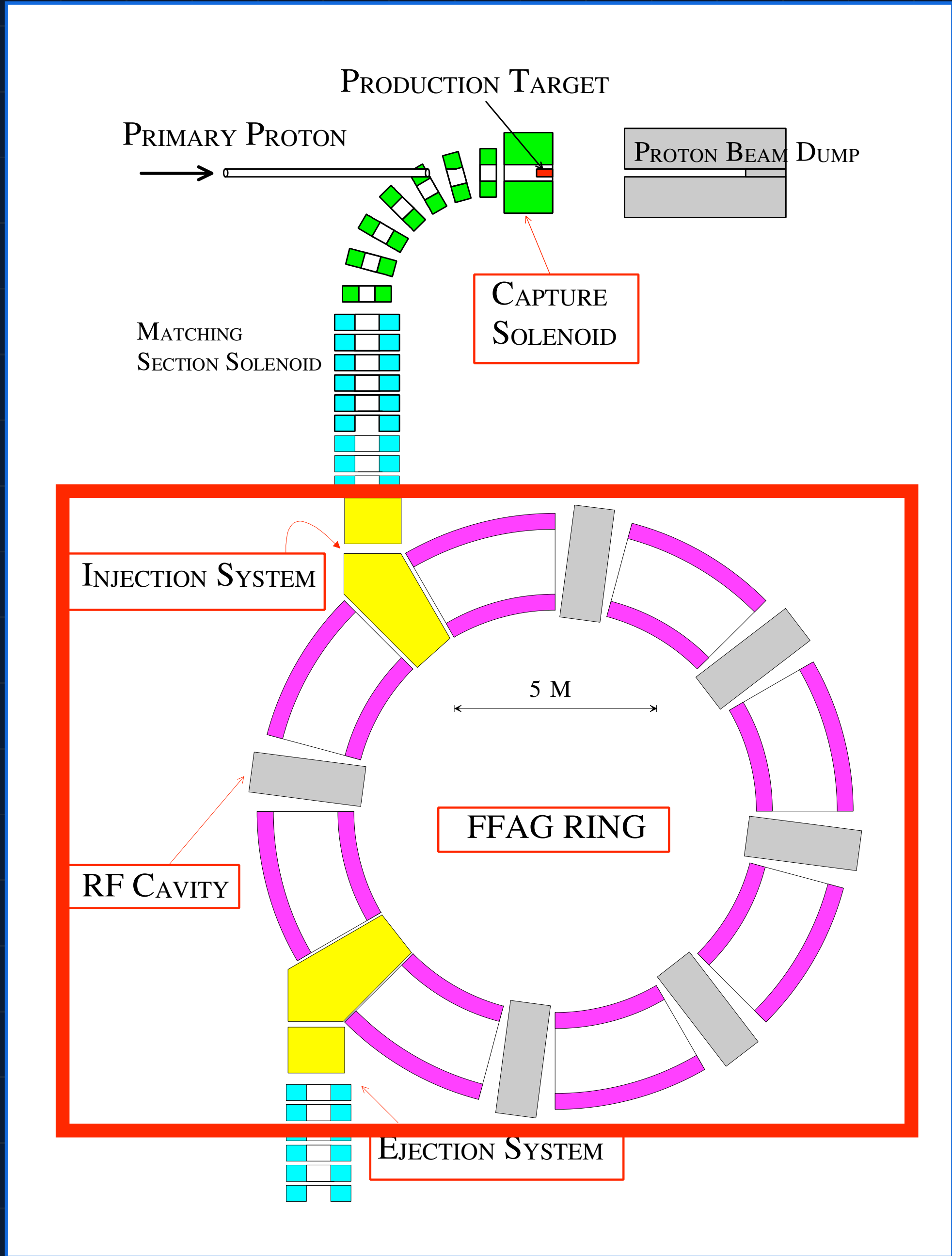
- Pion caoture section
- Decay section
- Phase rotator

FFAG advantages:

synchrotron oscillation
  necessary to do phase rotation
large momentum acceptance
  necessary to accept large momentum distribution at the beginning to do phase rotation
large transverse acceptance
  muon beam is broad in space

Ring advantages:

reduction of # of rf cavities
reduction of rf power consumption
compact

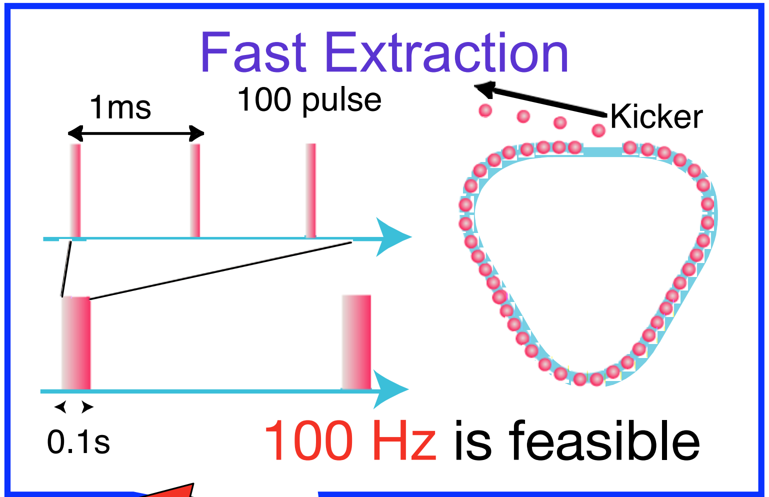


Pulsed Proton Beam Facility at J-PARC

50GeV-PS at J-PARC

- High intensity 0.75 MW
  - □ 10^{14}proton/sec
  - □ Upgradable to 4×10^{14}proton/sec
- A narrow bunched :

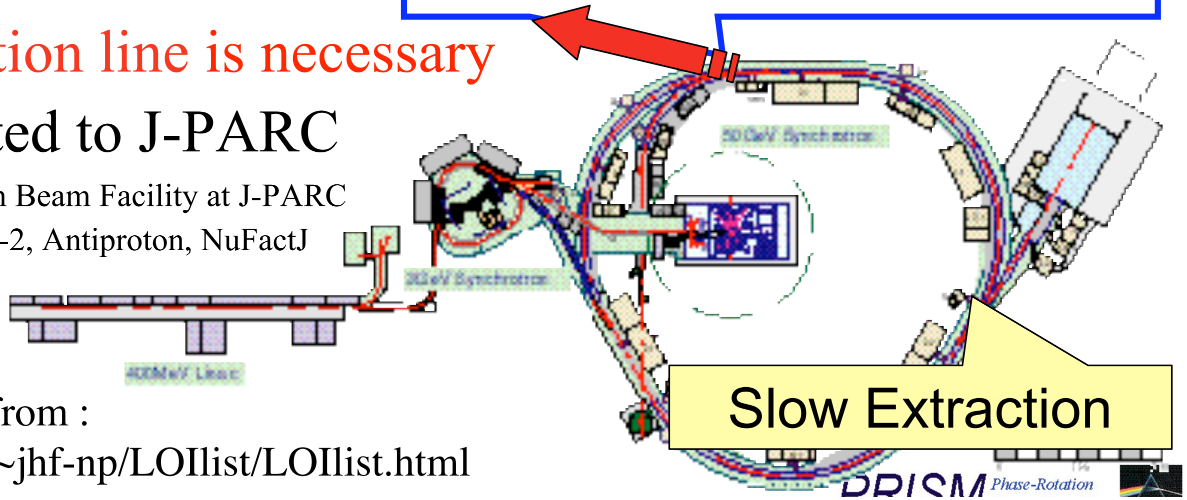
  for phase rotation



New Fast extraction line is necessary

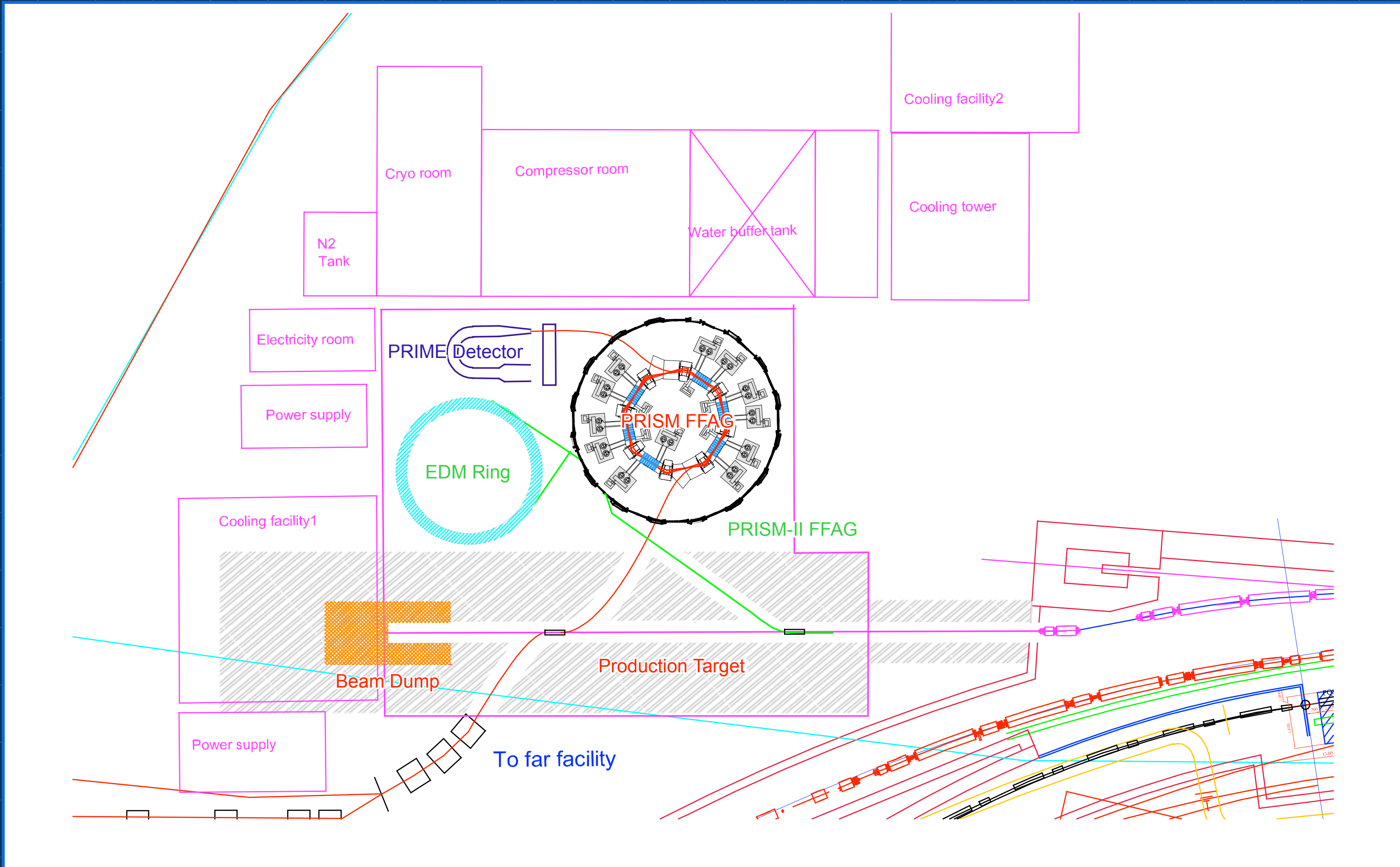
LOI was submitted to J-PARC

Request for A Pulsed Proton Beam Facility at J-PARC
PRISM/PRIME, EDM ,g-2, Antiproton, NuFactJ



LOIs are available from :
http://psux1.kek.jp/~jhf-np/LOIlist/LOIlist.html

PRISM @ J-PARC



Cooling facility2
Cryo room
Compressor room
Water buffer tank
Cooling tower
N2
Tank
Electricity room
PRIME Detector
Power supply
PRISM FFAG
EDM Ring
Cooling facility1
PRISM-II FFAG
Production Target
Beam Dump
Power supply
To far facility

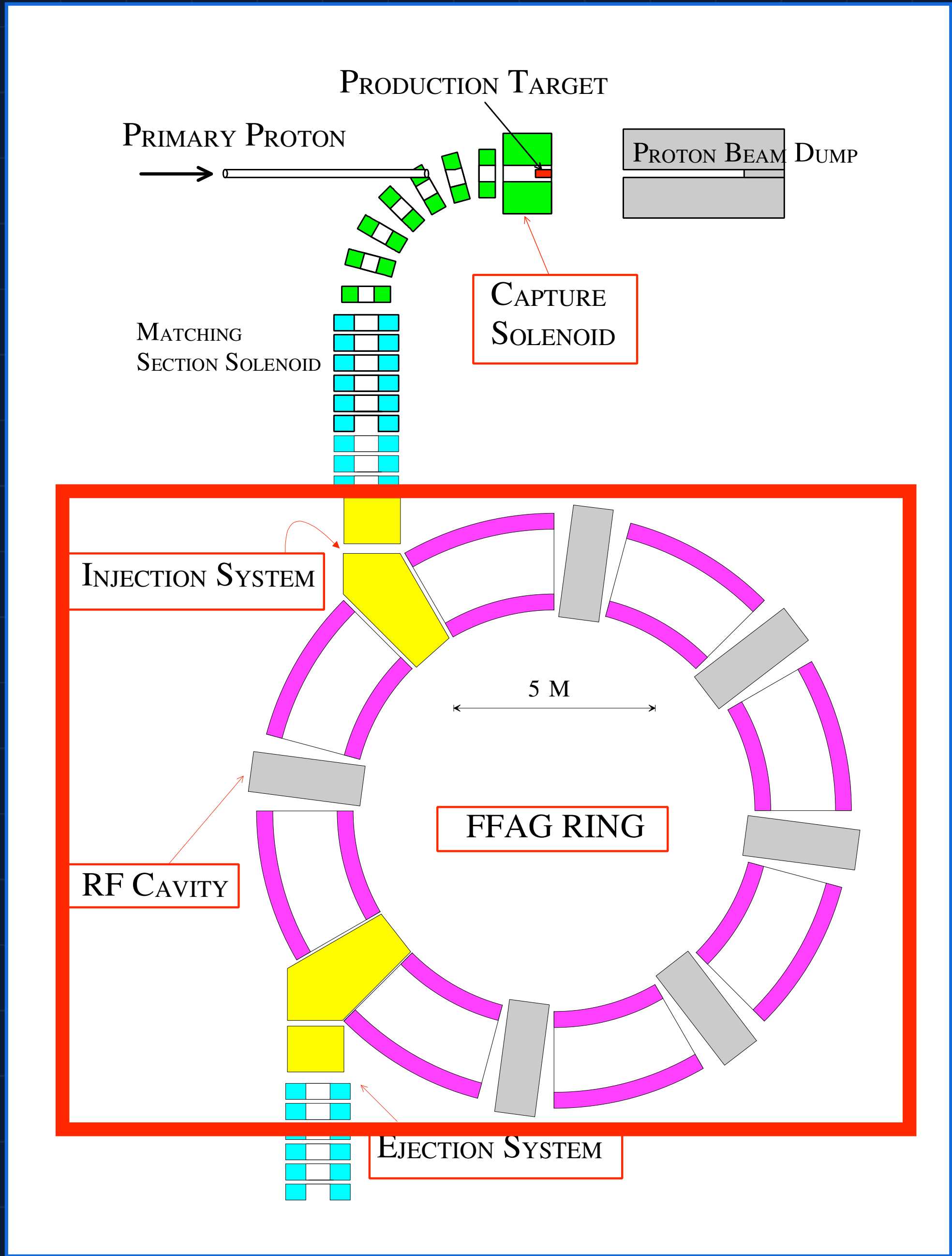
Features of PRISM-FFAG

- Large acceptance
  - H : >20000π mm mrad
  - V : >3000π mm mrad
- Quick phase rotation (～1μs)
  - Compact magnet
  - RF field gradient ~200kV/m
    - ~2MV/turn
- scaling FFAG
- F/D : variable
- magnetic field index (k value) : variable

FFAG construction

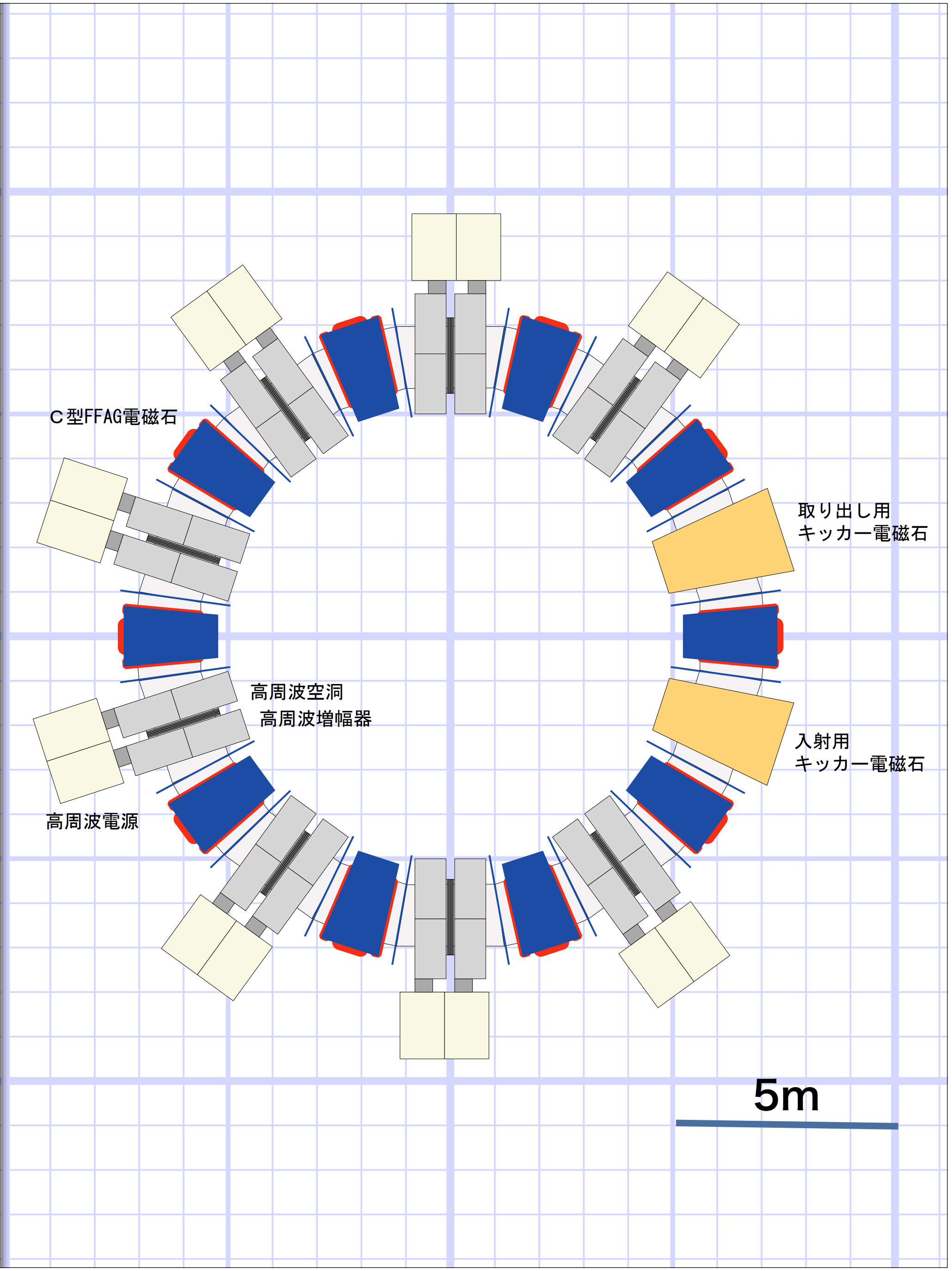
A budget for the PRISM-FFAG has been approved ! FY2003-FY2007

- to demonstrate
  - phase rotation
  - muon acceleration
  - ionization cooling
- R&D components
  - Large acceptance FFAG
  - high field gradient RF



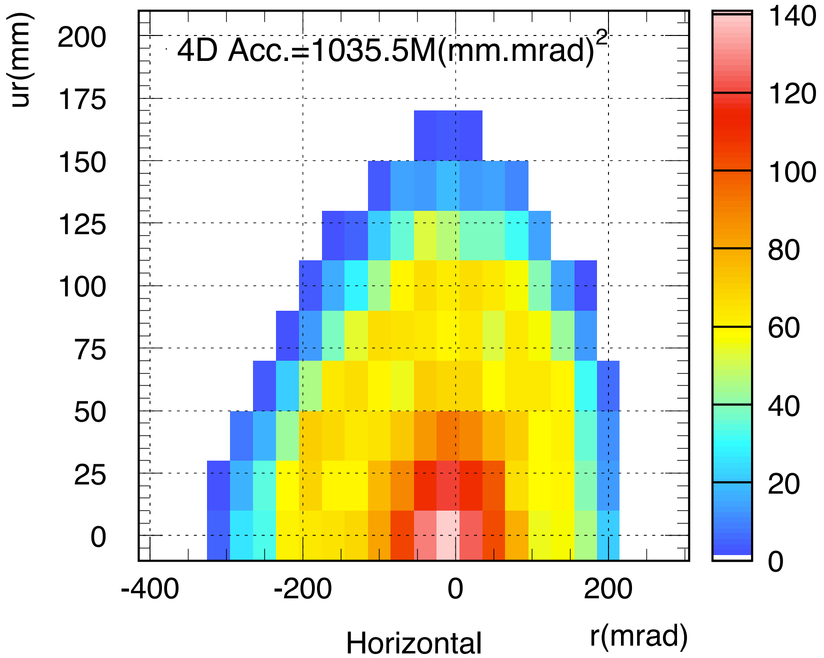
PRISM-FFAG Lattice

- N=10
- k=5(4.6-5.2)
- F/D(BL)=6
- r0=6.5m for 68MeV/c
- half gap = 17cm
- mag. size 110cm @ F center
- Triplet
  - θ_F=2.2deg
  - θ_D=1.1deg
- tune
  - h : 2.71
  - v : 1.52

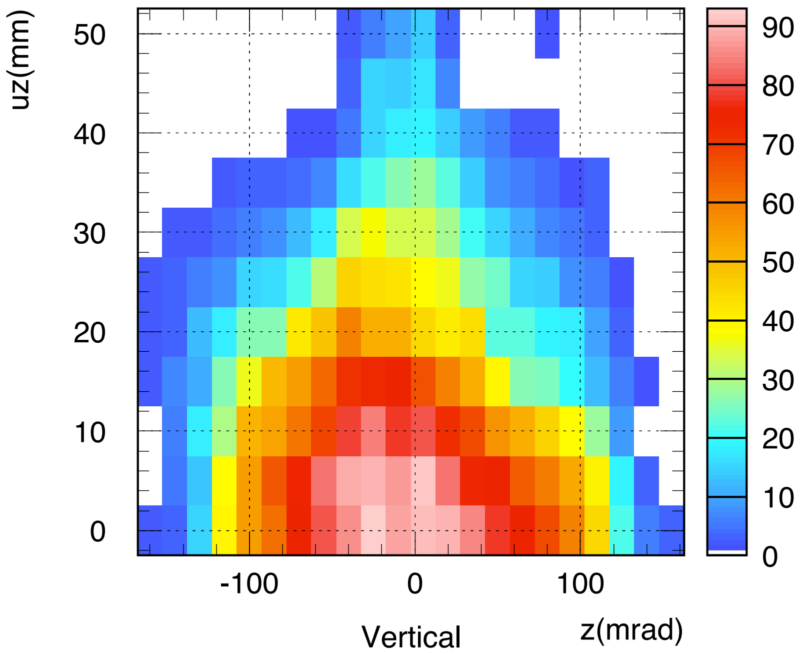


FFAG Acceptance

4D Acceptance： 1G (mm mrad)^2



Horizontal Acceptance
40000π mm mrad



Vertical Acceptance
6500π mm mrad

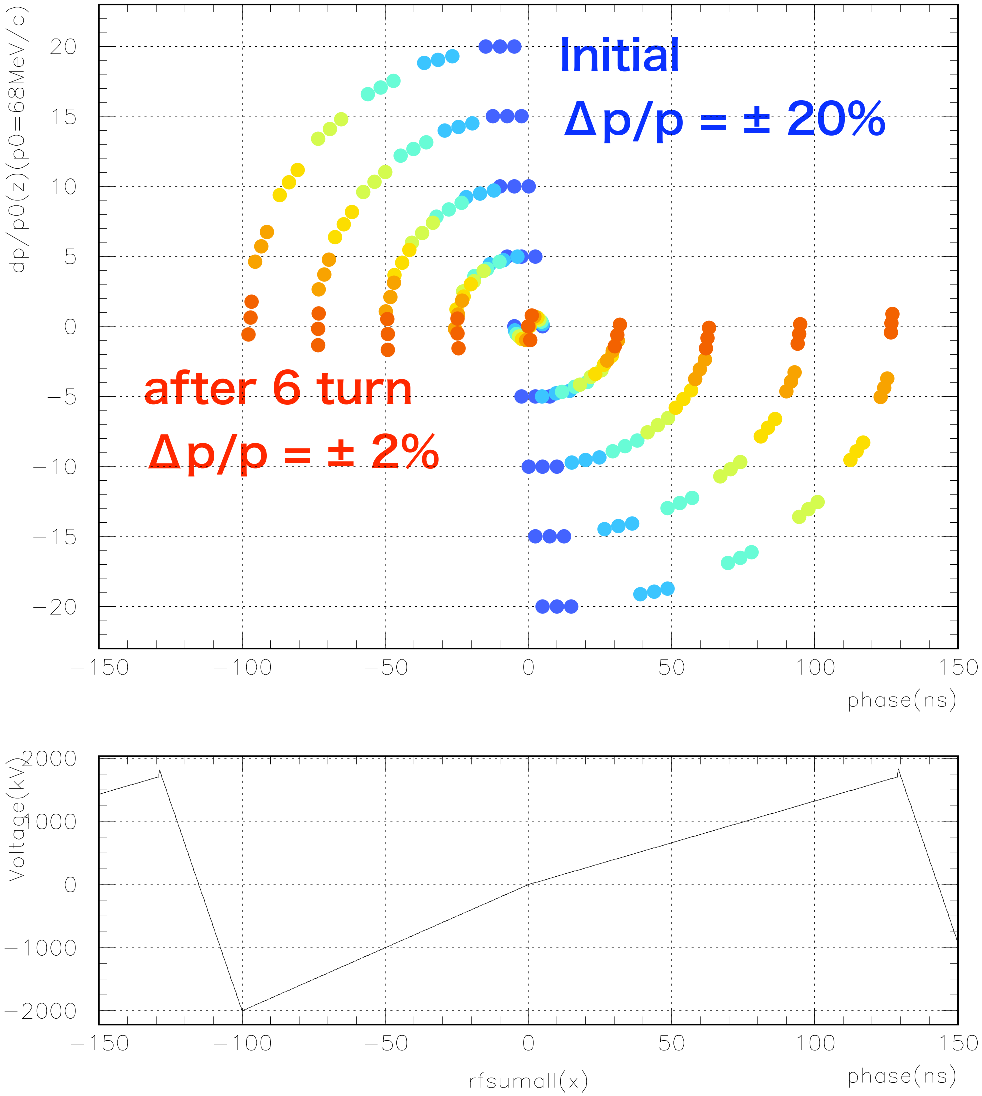
Phase Rotation Simulation

momentum spread
$\Delta p/p = \pm 2\%$

needs 6 turns ($=1.5\mu s$)

survival rate (68MeV/c)
μ : 0.56
π : $<10^{-23}$

no pion contamination



Simulation result
field gradient = 152kV/m

Magnet design

scaling radial sector

Conventional type. Have larger circumference ratio.

triplet (DFD)

F/D ratio can be tuneable. the field crump effects. large packing factor. the lattice functions has mirror symmetry at the center of a straight section.

large aperture

important for achieve a high intensity muon beam.

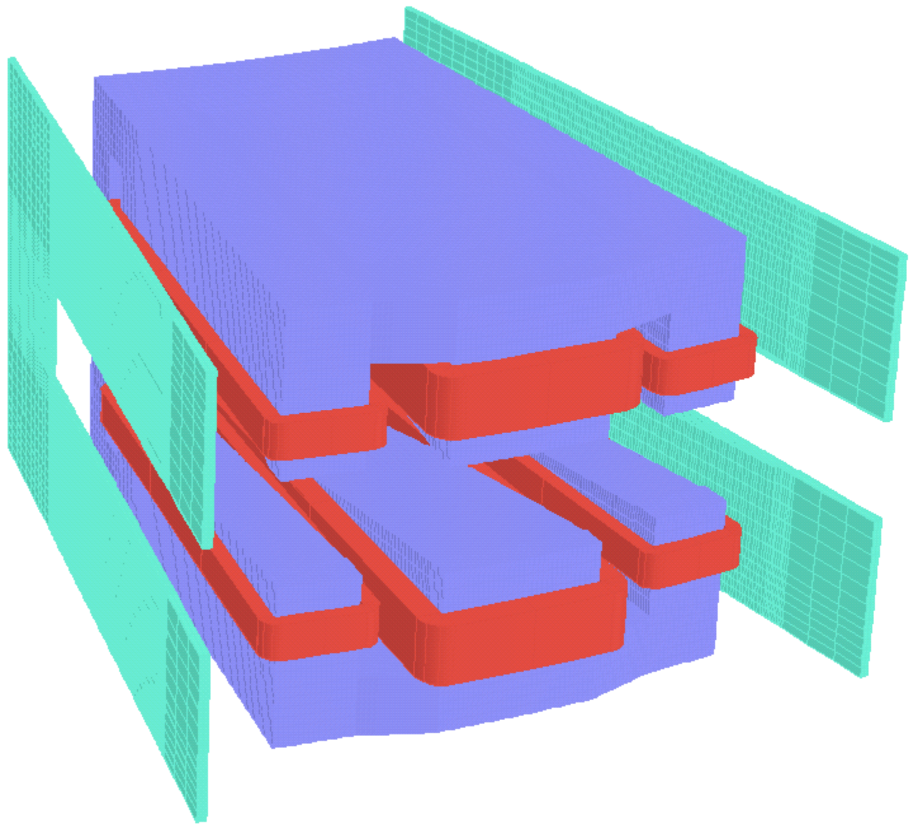
thin

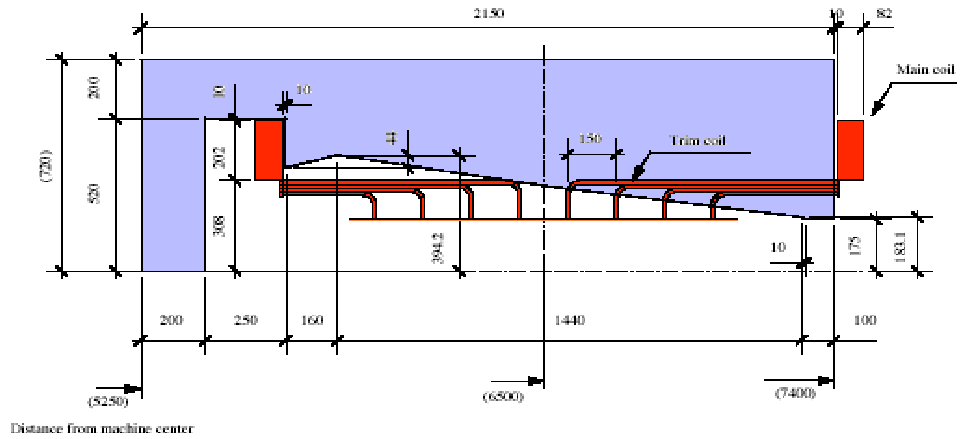
Magnets have small opening angle. so FFAG has long straight section install RF cavities as mach as possible

trim coils

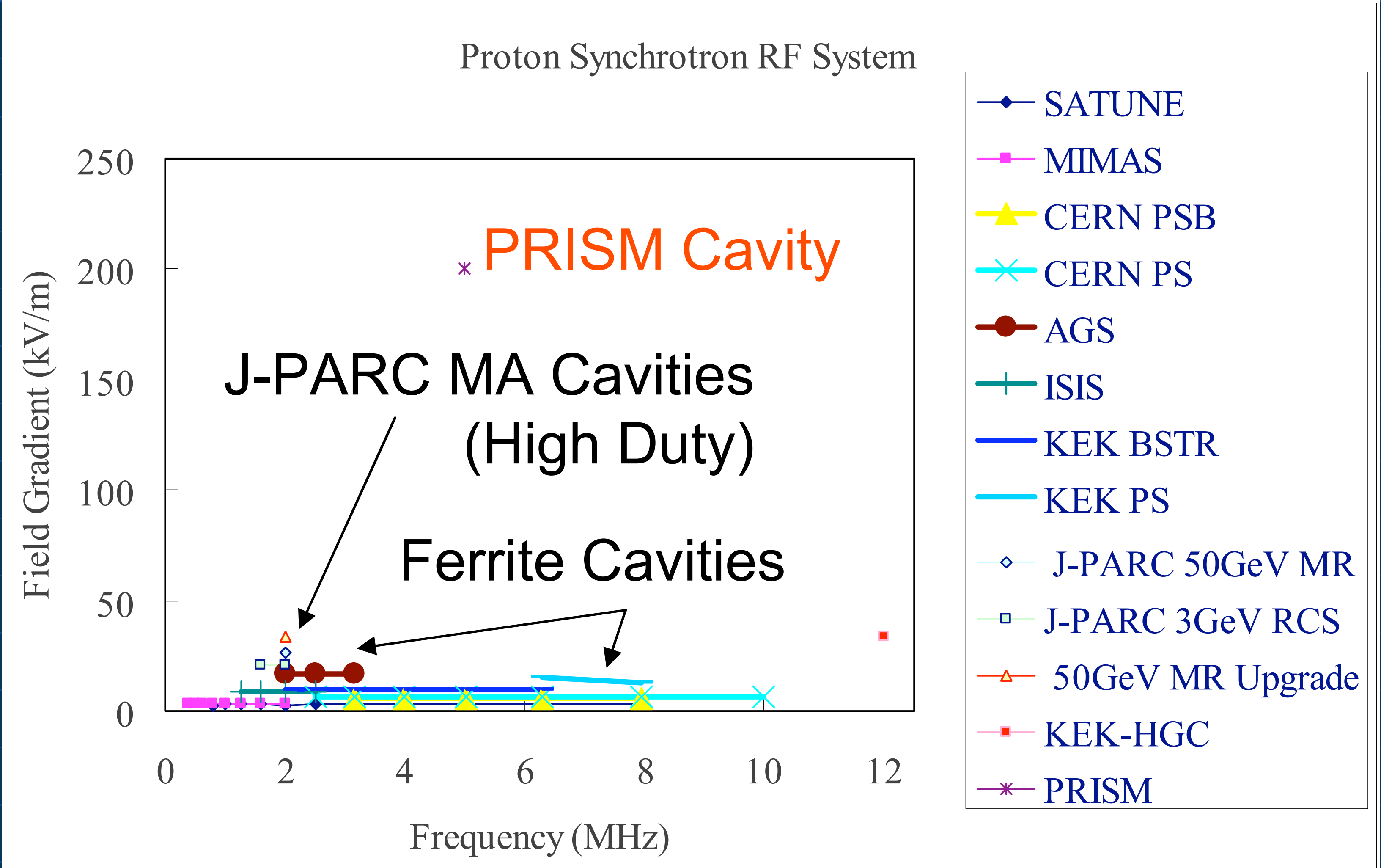
k value is tuneable. Therefore, not only vertical tune and also horizontal tune are tuneable.

C-shaped





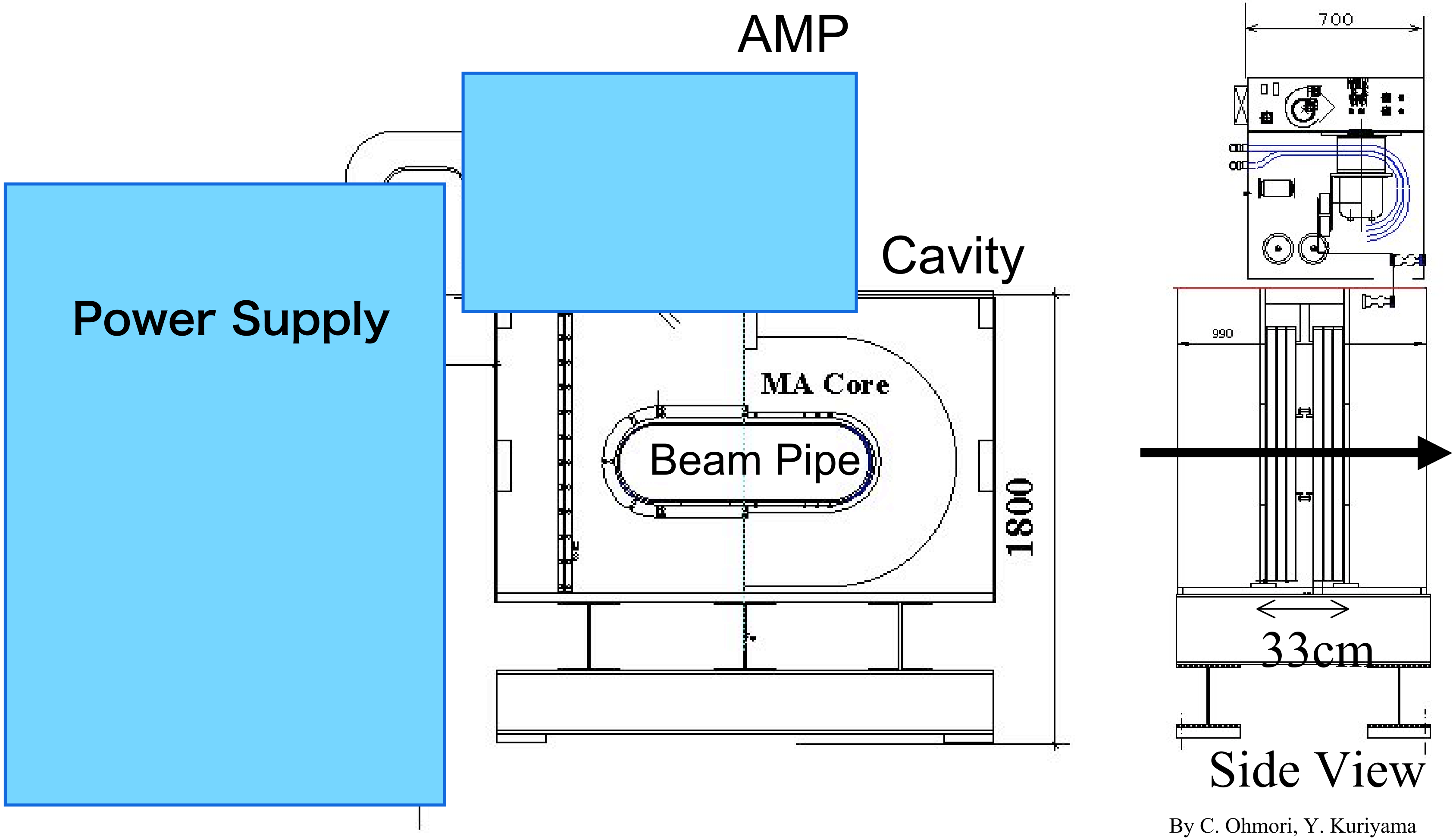
High field gradient RF



Number of gap per cavity	5
Length of cavity	1.75 m
Number of core per gap	6
Core material	Magnetic Alloy
Core shape	Racetrack
Core size	1.4m $\times$ 1.0m $\times$ 3.5cm
Shunt impedance	$\sim$159Ω/core @ 5MHz
RF frequency	4$\sim$5MHz
Field gradient	200kV/m
Flux density in core	320 Gauss
Tetrode	4CW150,000E
Duty	$<$0.1%

Table 3: Parameters of PRISM-FFAG RF system.

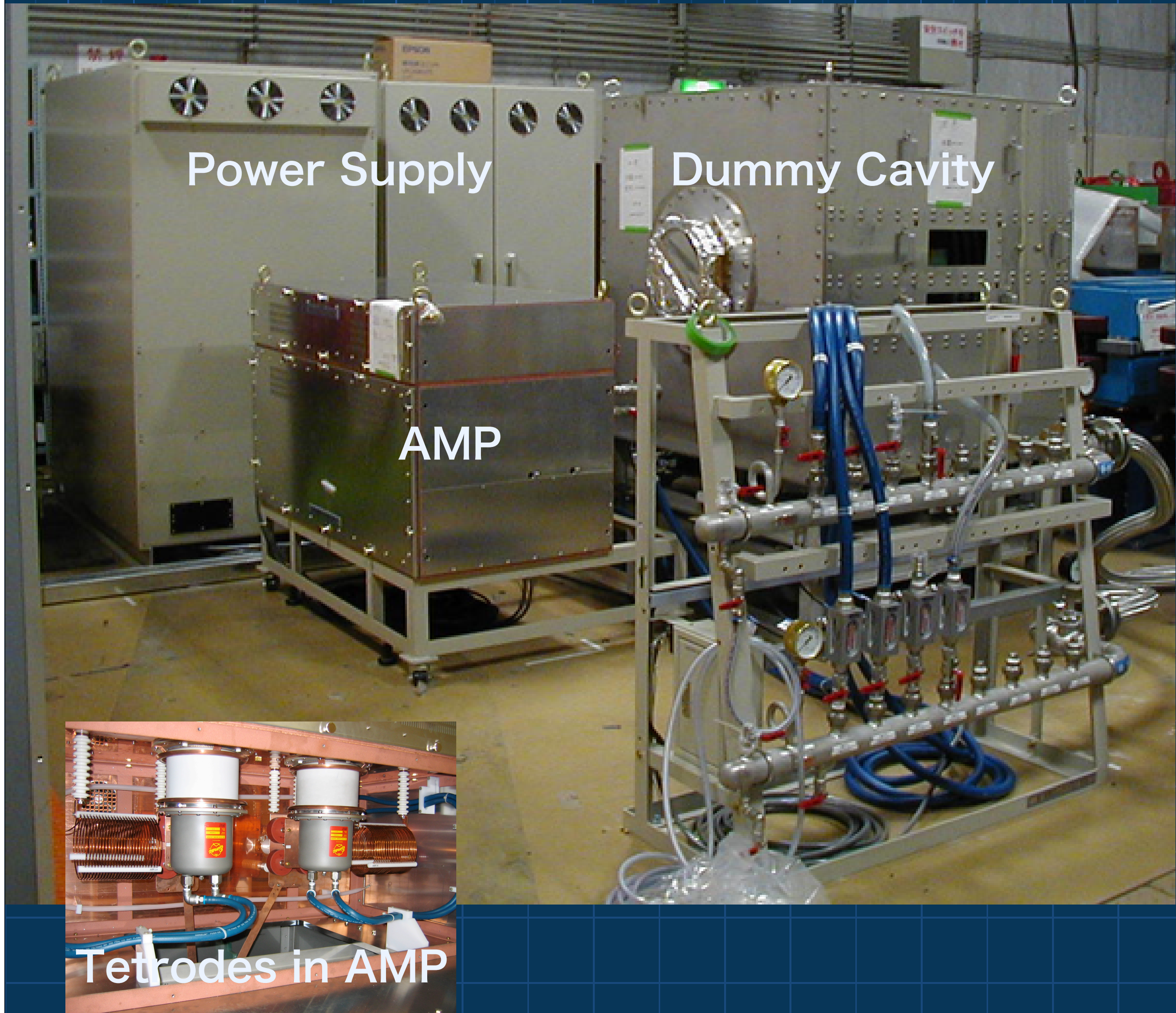
PRISM-RF System

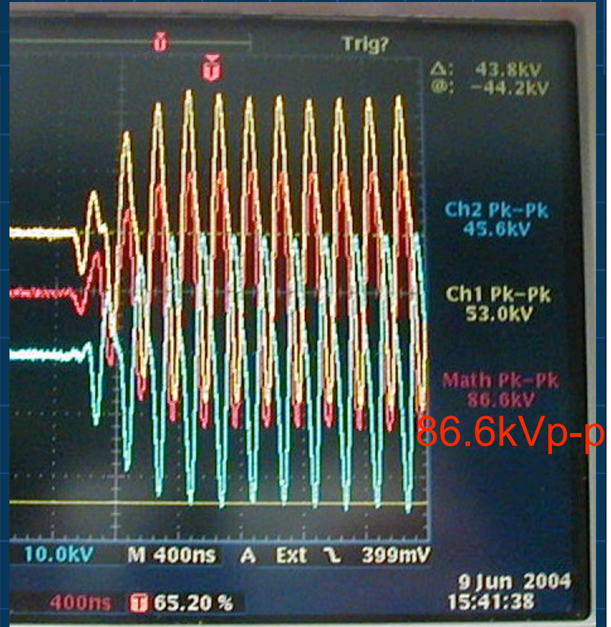


By C. Ohmori, Y. Kuriyama

A Prototype cavity with 1 gap will be ready by the end of this JFY.

RF AMP R&D

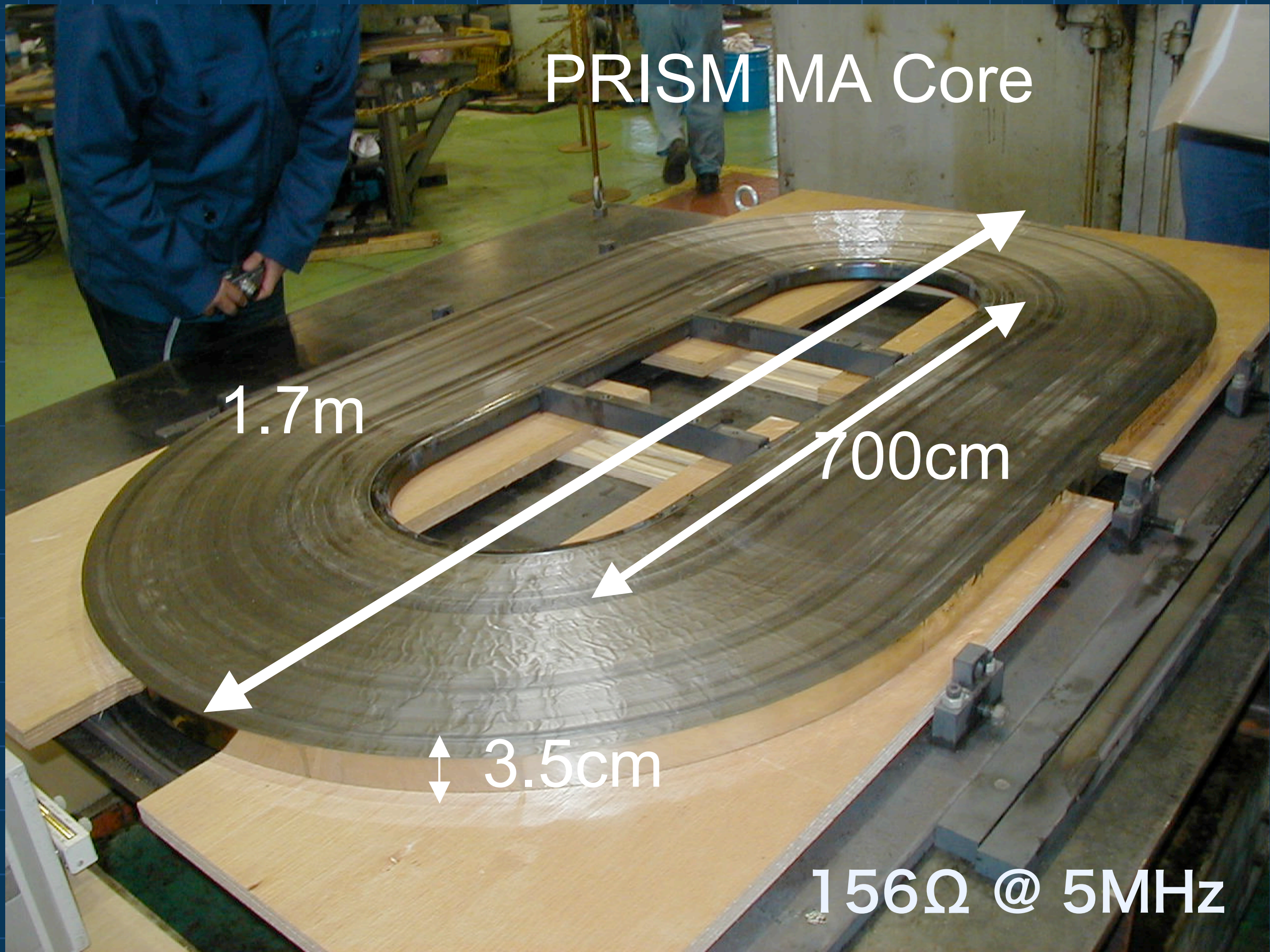




43kV/gap
w/ 734Ω dummy cavity
@5MHz

expected gradient
w/ PRISM-cavity (900Ω)
165kV/m

RF core (Magnetic Alloy)



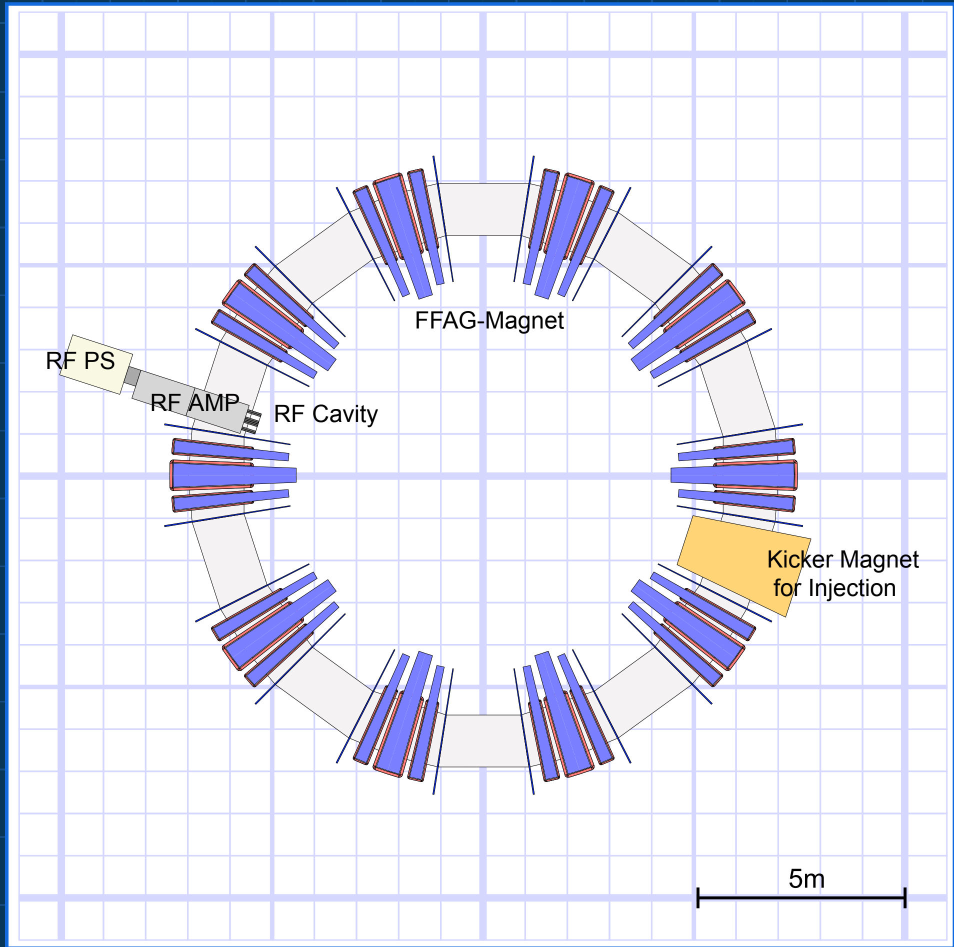
Construction Schedule

FY2003
- Lattice design, Magnet design
- RF R&D

FY2004
- RFx1gap construction & test
- Magnetx1 construction

FY2005-2006
- RF tuning
- Field measurement
- Magnetx9 construction
- FFAG-ring construction
- Commissioning
- Phase rotation

FY2007
- Muon acceleration
- (Ionization cooling)



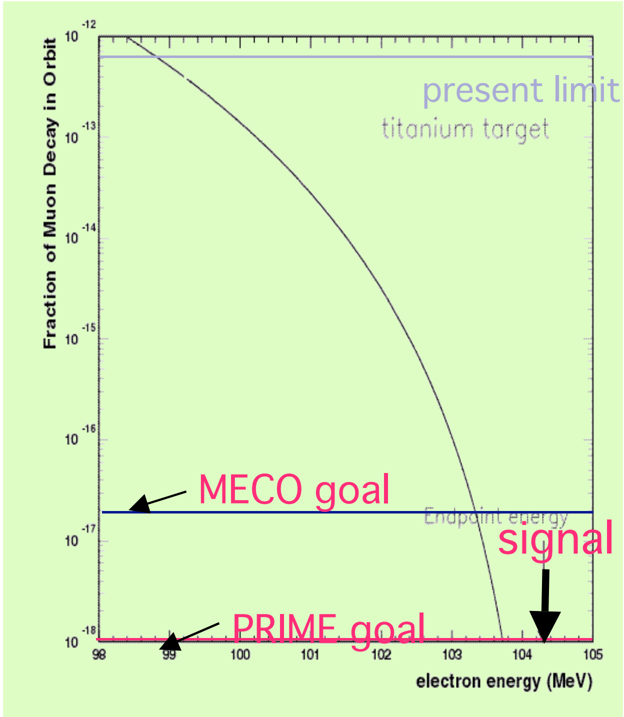
μ-e conversion experiment using PRISM

PRIME : PRIsm Mu-E conversion

aimed BR ~10^{-18}

Expected Background @ PRIME

Background	Rate	comment
Muon decay in orbit	0.05	energy reso 350keV(FWHM)
Radiative muon capture	0.01	end point energy for Ti=89.7MeV
Radiative pion capture	0.03	long flight length in FFAG, 2 kicker
Pion decay in flight	0.008	long flight length in FFAG, 2 kicker
Beam electron	negligible	kinematically not allowed
Muon decay in flight	negligible	kinematically not allowed
Antiproton	negligible	absorber at FFAG entrance
Cosmic-ray	< 10^-7 events	low duty factor
Total	0.10	



Reduce the detector rate

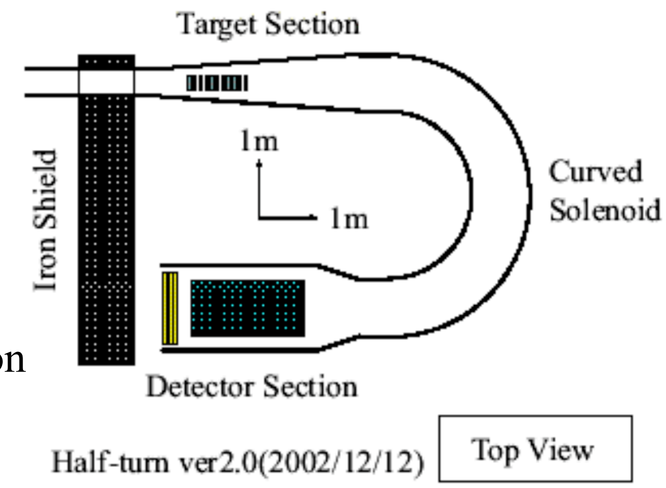
Curved Solenoid Spectrometer

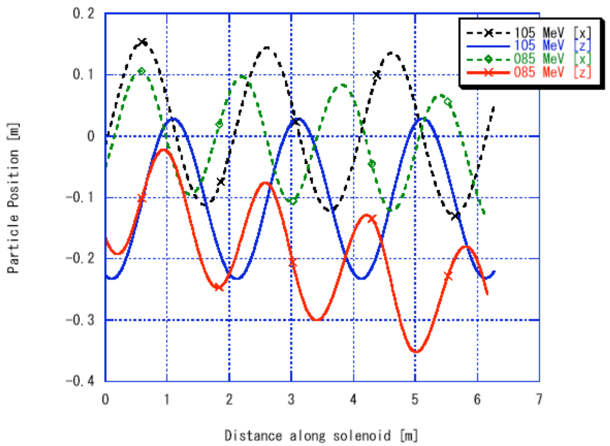
select a charged particle with a desired mom.

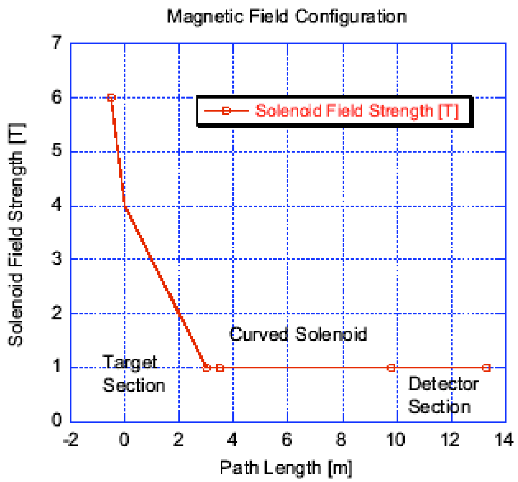
- Extract signal region only
  - Curvature drift

$$D = 1./(0.3B) \times s/R \times \frac{(p_s^2 + 0.5p_t^2)}{p_s}$$

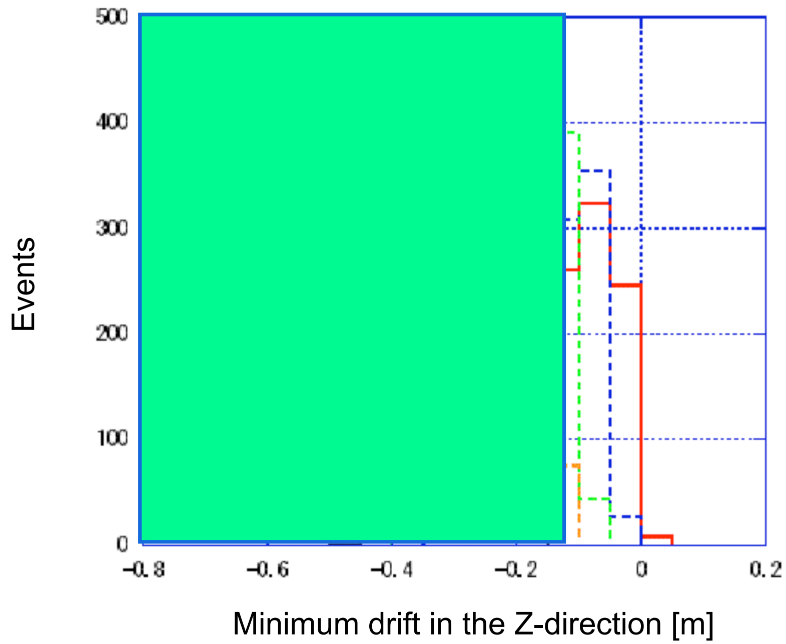
  - impose auxiliary field along the drift direction
  - Block unwanted particles
    - Positive
    - DIO (P<90 GeV/c)
- Reduce background and single rate

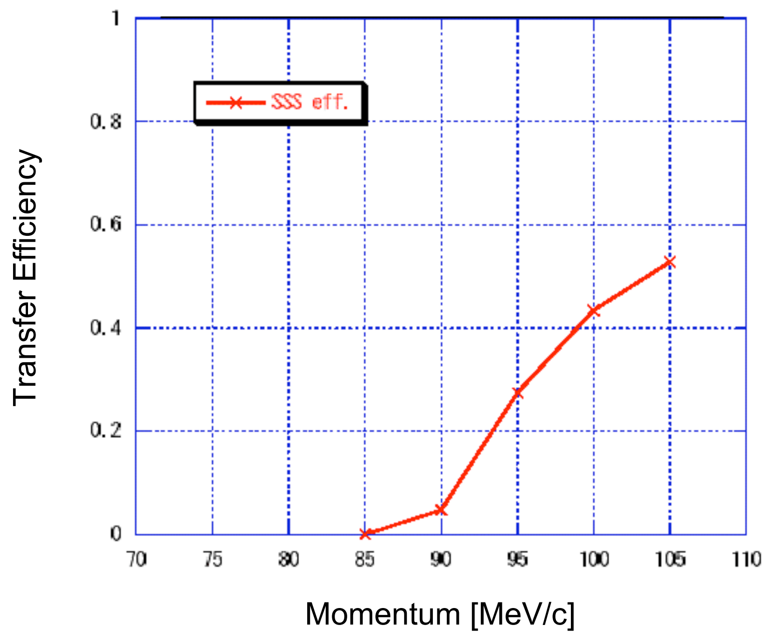






Curved Solenoid Spectrometer
- Transport Efficiency -





* 53% of signal event can be transported successfully
* Background rate is low

Muon yield

- Estimated by using MC simulation.
- depends on the technology choice. ; target, field magnitude ,,,
- Not fully optimized yet.

Target material	Capture field	Transport field	Muon yield per 10^{14} protons	Muon yield per 4×10^{14} protons
Graphite	16 T	4 T	4.8×10^{10}	19×10^{10}
	16 T	2 T	3.6×10^{10}	14×10^{10}
	12 T	4 T	3.6×10^{10}	14×10^{10}
	12 T	2 T	3.0×10^{10}	12×10^{10}
	8 T	4 T	3.0×10^{10}	12×10^{10}
	8 T	2 T	2.4×10^{10}	9.6×10^{10}
	6 T	4 T	1.8×10^{10}	7.2×10^{10}
	6 T	2 T	1.8×10^{10}	7.2×10^{10}
Tungsten	16 T	4 T	$\boxed{13 \times 10^{10}}$	50×10^{10}
	16 T	2 T	11×10^{10}	46×10^{10}
	12 T	4 T	9.6×10^{10}	38×10^{10}
	12 T	2 T	9.0×10^{10}	36×10^{10}
	8 T	4 T	6.0×10^{10}	24×10^{10}
	8 T	2 T	7.2×10^{10}	29×10^{10}
	6 T	4 T	4.2×10^{10}	17×10^{10}
	6 T	2 T	4.8×10^{10}	19×10^{10}

Target length
3 interaction length
FFAG acceptance
H:20000πmm mrad
V:3000π mm mrad
$\varepsilon_{dispersion} = 100\%$
$\varepsilon_{FFAG} = 100\%$

PRIME vs MECO

	PRIME	MECO
Intensity (muons/sec)	1.3x10^11/sec	2X10^11/sec
Muon momentum	68 ± 2 MeV/c	15-90 MeV/c
mu stopping efficiency	80%	40%
Target material	Ti (life time=329 ns)	Al (life time=880 ns)
Physics Sensitivity	B(muN=>eN)/B(mu=>eg) =1/238	B(muN=>eN)/B(mu=>eg) =1/389
Target arrangement	20 layers of 50 um plate	(17-25) layers of200 um plate
Energy loss in target	<150 keV(FWHM)	636 keV(FWHM)
Spectrometer resolution	235 keV (FWHM)	900 keV (FWHM)
Spectrometer acceptance	35%	20%
Time window	Full time window (100%)	Delayed window (50%)
Beam Purity	mu only	mu, pi and e
Single event sensitivity	6x10^-19	2x10^-17
Remark	5 year (=10^7 sec/year) running time; Analysis eff of 0.8 assumed.	

Summary

- **PRISM** will provide super muon beam : low energy, high intensity, narrow energy spread and high purity.
- **PRIME** is an experiment to search for mu-e conversion at 10^{-18} using PRISM.
- A program to construct a PRISM-FFAG has been started in 2003.